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Title: “Publication Trends Over 55 Years of Behavioral Genetic Research”

Running Head: “55 Years of Behavioral Genetic Research”

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Abstract

We document the growth in published papers on behavioral genetics for 5-year intervals from 1960 through 2014. We used 1,861 papers published in *Behavior Genetics* to train our search strategy which, when applied to Ovid *PsychINFO*, selected more than 45,000 publications. Five trends stand out: (1) The number of behavioral genetic publications has grown enormously; nearly 20,000 papers were published in 2010-14. (2) The number of human quantitative genetic (QG) publications (e.g., twin and adoption studies) has steadily increased with more than 3,000 papers published in 2010-14. (3) The number of human molecular genetic (MG) publications increased substantially from about 2,000 in 2,000-04 to 5,000 in 2005-09 to 9,000 in 2010-14. (4) Nonhuman publications yielded similar trends. (5) Although there has been exponential growth in MG publications, both human and nonhuman QG publications continue to grow. A searchable resource of this corpus of behavioral genetic papers is freely available online at http://www.teds.ac.uk/public_datasets.html and will be updated annually.

Introduction

Although the origins of behavioral genetic research trace back to Francis Galton in the 19th century (Galton, 1869), the modern era can be conveniently marked with the field-defining book, *Behavior Genetics* by Fuller and Thompson in 1960. The growth of behavioral genetic research since then is accelerating as the use of genetically sensitive designs such as twin and adoption studies permeates all

domains of behavioral science (Knopik et al. in press). The rapid advances in research using DNA itself seems to have fueled even greater growth during the past decade.

The purpose of this paper is to document the growth of behavioral genetic research publications since 1960 and to create a searchable resource. We compare growth in quantitative genetic (QG) and molecular genetic (MG) human and nonhuman research. Our search for scientific publications on behavioral genetics found over 45,000 publications from 1960 through 2014 on which we based these analyses. We have compiled these references (authors, title, journal, year) with their abstracts, key words and PubMed ID/DOI numbers in an online resource, (the *Behavioral Genetics index, BGi*), that is freely available and searchable and which will be updated on an annual basis:

http://www.teds.ac.uk/public_datasets.html.

Method

Our goal was to identify all published papers between 1960 and 2014 on the genetics of human and non-human behavior, including both quantitative and molecular genetic studies. We searched for publications using the search engine Ovid, selecting the most up-to-date version of the database *PsychINFO*.

PsychINFO includes more than 4 million records from more than 2,500 journals that, at least occasionally, publish papers related to behavior. We limited our search to *PsychINFO* to make the task more manageable, although we admit that *PsychINFO* misses some behavioral genetic papers among the 1 billion records

including an additional 10,000 journals, for example, covered by the *Science Citation Index*.

In our search, we specified *journal article* or *review* only. We excluded conference presentations for two reasons: they rarely include abstracts, which would make them difficult to categorize, and they are often later published as papers, which would result in duplication.

Definitional issues and search criteria complicate the search for published papers on behavioral genetics. Definitional issues begin with the basic questions ‘what is behavior?’ and ‘what is genetics?’. We are confident that the bulk of papers that we selected would meet anyone’s definition of behavioral genetics – for example, twin studies or DNA association studies of psychopathology, personality and cognitive abilities and disabilities. However, problems emerge at the borders. Our aim was to be inclusive within reasonable bounds in order to capture most behavioral genetic publications. For example, if behavior is defined as observable activity of an organism rather than a particular organ, then what about neuroimaging studies of brain activity? We included these papers, although we attempted to exclude publications that refer to the ‘behavior’ of cells or molecules. We also excluded papers that looked at methodological issues without specifying a phenotype. The word *genetic* is especially far-reaching, but we focused on the inheritance of individual differences within a species, excluding, for example, research on average genetic differences between species.

It is also difficult to avoid arbitrariness in selecting search criteria to identify papers that fall within these broad definitional boundaries of behavioral genetics. In our online resource, we include the actual search terms used, which will facilitate the use of different criteria. We expect that few will object to the papers we have selected, although some might wish to cast a wider net.

We avoided some of these definitional and search criteria issues by ‘training’ our search strategy on the 2,107 papers in the journal *Behavior Genetics* from 1960 to 2014 (for a flow diagram of the search process, see Supplementary Figure S1). Following our inclusion criteria above, we omitted 247 papers, resulting in a total of 1,861 publications. By using the journal *Behavior Genetics*, we make the assumption that papers published in this journal define research on behavioral genetics. We began by coding these papers as human, non-human, quantitative genetic (e.g., twin and adoption studies) and molecular genetic (e.g., linkage and association studies) and identified those papers that fell into more than one category. We refined the search strategies for these four categories until we could no longer improve the results. (The final search codes are listed in Supplementary Methods S1.) We then applied these search terms to publications in *Behavior Genetics*. Although *Behavior Genetics* was the journal on which our search terms were trained, we conducted this analysis for three reasons. First, this test indicates the best possible results that could be expected when we applied these search terms to other journals. Second, the 1,861 papers in *Behavior Genetics* were a manageable number for manual coding. Third, we could determine false negative rates because all the ‘correct’ papers had been identified.

We then applied these search strategies to the *PsychINFO* database. The arbitrariness of definitions and search terms and the inclusion of false positives is not likely to jeopardize our results documenting the growth of research in behavioral genetics because the same criteria were applied across all years.

Results

Training search criteria on the journal *Behavior Genetics*

The results for our training of search criteria using the *Behavior Genetics* journal are presented in Table 1. When combining search codes for all categories we recovered 83% of the 1,861 papers published in *Behavior Genetics* (see Table 1). Our individual codes for the four categories recovered the following percentage of papers: 84% human quantitative, 78% human molecular, 76% non-human quantitative, and 82% non-human molecular. Based on our coding, the percentage of papers that were incorrectly identified in the four categories (false positives) were 4%, 17%, 8%, and 14%, respectively (see Table 1). False positives primarily consisted of miscategorizations, for example, when a quantitative genetic paper was classified as a molecular genetics paper. Publications that were not picked up by our code – for example, papers where our keywords did not appear in the title or abstract – were classified as false negatives.

In Table 1, the sum of publications from individual codes (1,886) exceeded the total number of papers in our training database (1,861). This discrepancy occurs because 1% of papers were correctly classified into more than one category, for example, a quantitative family study that also used linkage analysis.

 << Insert Table 1 here >>

Applying the search criteria to *PsychINFO*

Our search criteria, trained on *Behavior Genetics*, yielded 46,941 papers from 1,917 journals including *Behavior Genetics* when applied to Ovid *PsychINFO*. Spot-checking 10% of these publications indicated that, on average, 76% of the search results were correctly selected and assigned to one of the four categories (see Table 2, which shows an average false positive rate of 25%). Based on this spot-check, we can estimate that around 36,800 publications are ‘true’ behavioral genetics papers. Rather than attempting to refine these results manually, we chose to accept the false positives, which has the advantage of keeping the search completely objective and also facilitating regular updates.

For our wider search in Ovid *PsychINFO*, the sum of publications (48,571) from individual codes exceeded the total number of papers captured when we combined the codes with the Boolean operator ‘OR’ (46,941). This indicates that 3.5% of the identified papers fall into more than one category, which includes

papers that combine human and nonhuman research as well as quantitative and molecular genetics.

 << Insert Table 2 here >>

Figure 1 shows the growth in publications by lustrum since 1960. After a slow start in the 1960s and 1970s, the number of publications has rapidly grown. From 1995 onwards, the number of publications has almost doubled every 5-year interval, with nearly 20,000 papers published during 2010-14.

 << Insert Figure 1 here >>

Although only 3% of the 46,941 papers were published in *Behavior Genetics*, that percentage has decreased dramatically over the lustra (from 12% in 1970-89 to 4% in 1990-2009 and to 1% in 2010-14) as other journals have increased their publication of behavioral genetic research. Most of those journals are in psychology (37%) and psychiatry (12%), but now include fields as diverse as education, economics, political science, and sociology.

Figure 2 compares the number of publications in human QG and MG research. The number of QG publications has increased steadily, with more than 3,000 papers published in 2010-14. The most striking result is the increase in MG papers: from 2,034 in 2000-04 to 5,464 in 2005-09 to 9,406 in 2010-14.

<< Insert Figure 2 here >>

Figure 3 illustrates the number of nonhuman QG and MG publications. The number of QG publications has increased modestly since 1960, with 1,111 QG papers published during 2010-14. What is striking is the rapid increase in nonhuman MG publications during the last decade, from 1,227 papers in 2000-04 to 6,227 papers in 2010-14.

<< Insert Figure 3 here >>

Discussion

The growth of behavioral genetic publications signals a more balanced view in the behavioral sciences that recognizes the importance of genetic as well as environmental influences. It is also encouraging that behavioral genetic research

has permeated most of the behavioral sciences. Only 3% of the 46,941 publications were published in *Behavior Genetics* and this percentage has decreased from 12% in the 1970s and 1980s to 1% in 2010-14. Behavioral genetic papers are increasingly being published in other journals, not just in psychology and psychiatry, but also in fields as diverse as education, economics, political science and sociology.

Although the growth of molecular genetic research in recent years is especially striking, quantitative genetic research has also grown steadily. These two worlds of genetics are complementary. Quantitative genetic research reveals the net effect of genetic influence regardless of the number of genes involved, their effect sizes, or the complexity of their interactions. Molecular genetic research attempts to identify these genes of small effect, which raises the problem of missing heritability (Manolio et al., 2009). Although fewer than 3% of all papers combine quantitative genetic and molecular genetic strategies in our wider search, this percentage seems certain to increase as researchers capitalize on the complementarity of quantitative and molecular genetics. Moreover, these two worlds of genetics are coming together with the availability of genome-wide polygenic scores that capture some of the heritability of behavioral traits and disorders (Plomin and Simpson, 2013).

As noted earlier, a searchable resource of this corpus of behavioral genetic papers, the *Behavioral Genetics index* (BGi), has been compiled that includes references, abstracts, key words and PubMed ID/DOI:

http://www.teds.ac.uk/public_datasets.html. The BGi is freely accessible and

searchable online and will be updated annually. The search terms used to create this resource are included on the website; we welcome suggestions for improving the search.

Considering the striking finding that 15% of articles account for half of citations in the 1.8 million journal articles published each year (STM report, 2012), more attention needs to be given to searchability. Our work emphasizes three obvious suggestions for making behavioral genetic papers more searchable, which will also make papers more likely to be cited and thus to have greater impact. First, because key terms are central to searchability, they should be carefully chosen to specify phenotype, sample and method; distinctive characteristics of a paper that cannot be included in key words should be mentioned in the title or abstract because the main body of the journal article is not searched. Second, it helps an area if there is an agreed-upon name for it. For example, SNP-based heritability estimates have at least half a dozen different labels, which makes a search more difficult. In contrast, although there are many labels for polygenic scores, they nearly all contain the phrase *polygenic score*, which facilitates their search. Third, if key terms are composed of multiple words (e.g. “Family study”), these should appear adjacent to one another (e.g. “A family study of 300 siblings” instead of “300 siblings were studied in a family-based design”). Our online searchable resource can be used to test keywords proposed for a manuscript by entering these keywords to ensure that they select appropriate papers.

We have produced the largest comprehensive behavioral genetic database to date, documenting the field’s publications from 1960. However, we acknowledge

that our results include some incorrectly identified papers as indicated by the false positive rate in our spot-checks. As false positives are likely to be evenly distributed over the 55-year interval, this should not affect the trends observed. Another potential limitation is that we trained our search terms on the journal *Behavior Genetics*, which may have introduced biases.

Our online resource is of course limited to the quantity, not quality, of behavioral genetics papers. We acknowledge that the health of a field is judged more by the quality than the quantity of its research. However, we have argued elsewhere that the quality of research in behavioral genetics is also impressive (Plomin et al, in press). In contrast to the current crisis of failures to replicate results (Open Science Collaboration, 2015), behavioral genetic research has yielded robustly replicated findings that are large, both in terms of effect size and potential impact on science and society.

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Author Contributions

All authors conceived and designed the project. ZA, SS and ESW conducted the search. All authors participated in the writing and revising of the paper.

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Compliance with Ethical Standards:

Conflict of Interest: The authors report no conflict of interest.

Ethical Approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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Tables

Table 1. Keyword training descriptive statistics

| | BG database | Ovid results | Overlap | Overlap % | FP % | FN % |
|------------------------|------------------------|-------------------------|----------------|----------------------|-------------|-------------|
| Human QG | 738 | 649 | 619 | 83.9 | 4.1 | 16.1 |
| Human MG | 206 | 194 | 160 | 77.7 | 16.5 | 22.3 |
| Nonhuman QG | 605 | 497 | 457 | 75.5 | 8.2 | 24.5 |
| Nonhuman MG | 337 | 319 | 276 | 81.9 | 13.5 | 18.1 |
| Codes combined* | 1861 | 1542 | 1537 | 82.6 | < .01 | 17.5 |

BG database = number of publications in the journal *Behavior Genetics* for each category, Ovid result = number of publications yielded by the search scripts, Overlap % = the degree of overlap achieved, FP = false positives and FN = false negatives, *= codes combined is less than the sum of each category because we have captured only unique publications by using the Boolean operator 'OR'.

Table 2. Number of total findings from *PsychINFO* database search

| | Total results | FP % |
|--------------------|----------------------|-------------|
| Human QG | 11694 | 27 |
| Human MG | 18296 | 21 |
| Nonhuman QG | 6501 | 23 |
| Nonhuman MG | 12079 | 27 |

FP = false positives.

Figure Captions

Figure 1. Total number of behavioral genetic papers published in 5-year intervals since 1960.

Figure 2. Number of human behavioral genetic papers by lustrum since 1960, comparing quantitative and molecular genetic research.

Figure 3. Number of nonhuman behavioral genetic papers published by lustrum since 1960, comparing quantitative and molecular genetic research.

Figures

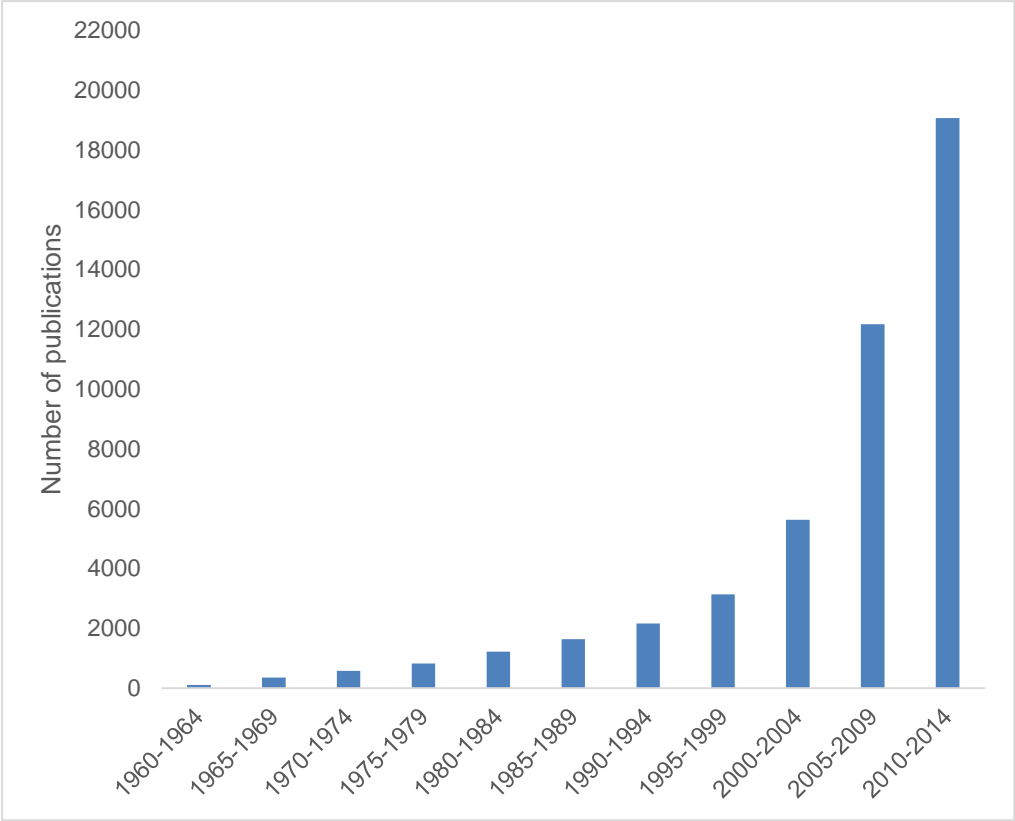


Figure 1. Total number of behavioral genetic papers published in 5-year intervals since 1960.

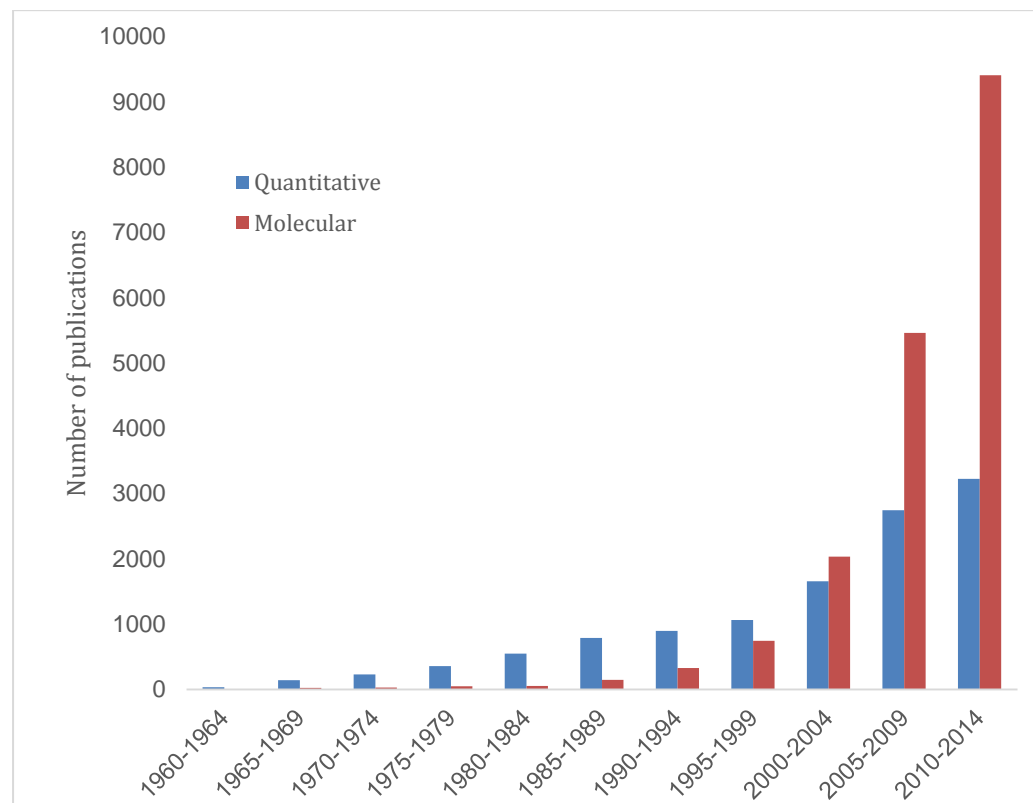


Figure 2. Number of human behavioral genetic papers by lustrum since 1960, comparing quantitative and molecular genetic research.

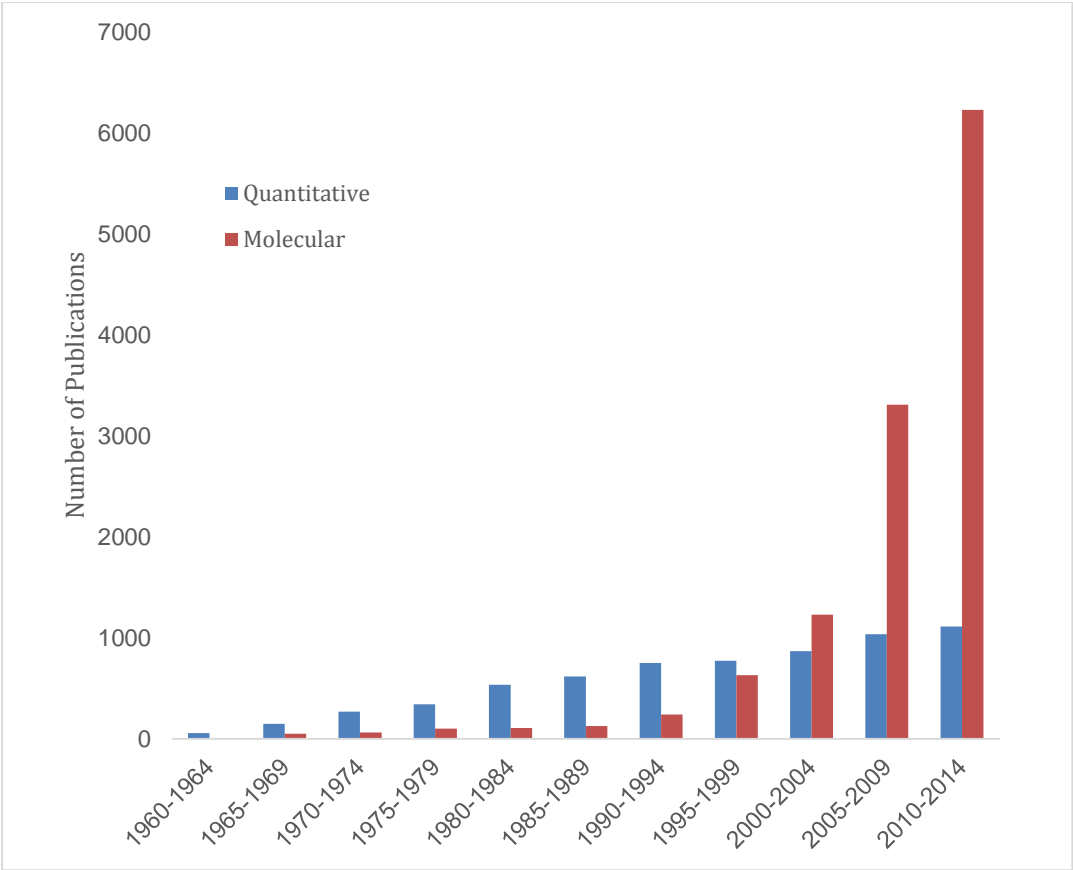


Figure 3. Number of nonhuman behavioral genetic papers published by lustrum since 1960, comparing quantitative and molecular genetic research.